Chapter 10

Blue-Green Infrastructure: New Frontier for Sustainable Urban Stormwater Management

Kuei-Hsien Liao, Shinuo Deng and Puay Yok Tan

Abstract Blue-green infrastructure (BGI) has been recognized as an important tool for sustainable urban stormwater management. BGI is ecosystem-based, relying on biophysical processes, such as detention, storage, infiltration, and biological uptake of pollutants, to manage stormwater quantity and quality. Rain gardens, bioswales, constructed wetlands, retention and detention basins, and green roofs are most commonly used BGI systems. Unlike the single-functioned grey infrastructure, which is the conventional urban drainage system, these landscape systems collectively provide multiple ecosystem services, including flood risk mitigation, water quality treatment, thermal reduction, and urban biodiversity enhancement. In recent years, BGI is increasingly embraced through different initiatives around the world, driven by the urgency to tackle different local challenges, such as water quality standards, water security, increased flood risk, and aquatic ecosystem degradation. Whereas BGI is a relatively new term, the idea and practice are not new. In this chapter, we also showcase four cities—Portland, New York City, Singapore, and Zhenjiang—that are active and progressive in implementing BGI. Although BGI receives increasing attention, mainstreaming BGI remains a challenge today. To promote widespread BGI implementation, future research should focus on case studies on practical BGI experiences to inform strategies for overcoming the barriers to mainstreaming BGI in different cities.

K.-H. Liao (✉) · P.Y. Tan
National University of Singapore, Singapore, Singapore
e-mail: kueihsienl@gmail.com; akiliao@nus.edu.sg

P.Y. Tan
e-mail: akitpy@nus.edu.sg

S. Deng
AECOM Asia Company Limited, Sha Tin, Hong Kong
e-mail: shinuo.deng@gmail.com

P.Y. Tan and C.Y. Jim (eds.), *Greening Cities: Forms and Functions*,
Advances in 21st Century Human Settlements,
DOI 10.1007/978-981-10-4113-6_10

Keywords Blue-green infrastructure · Sustainable stormwater management · Ecosystem-based solutions · Ecosystem services · Low-impact development · Urban drainage

10.1 Introduction

Managing urban stormwater is increasingly challenging as the world sees increasing urbanized areas and extreme storms. Stormwater runoff from the ever expanding impervious surfaces not only exacerbates flood risk but also further degrades the aquatic ecosystem that receives it. The problems and limitations of the conventional management approach to urban stormwater are well recognized. This has led to the emergence of ‘green infrastructure’ in recent years as a supplement and even an alternative to the existing ‘grey infrastructure’, which typically consists of roadside drains and sewers.

The term ‘green infrastructure’ commonly refers to a connected network of multi-functional green and open spaces that provide ecosystem services (Benedict and McMahon 2002). At the local scale, green infrastructure often refers specifically to sustainable stormwater management features that utilize natural processes, e.g., rain gardens, bioswales, constructed wetlands (Rouse and Bunster-Ossa 2013). The term ‘blue-green infrastructure’ (BGI) is also used, albeit less frequently. In this chapter, we discuss BGI as a particularly type of green infrastructure and define it as a network of landscape systems, which often combines both natural and artificial materials and is purposefully designed and managed to provide stormwater-related ecosystem services.

The essence of BGI as an approach to stormwater management is that it is ecosystem-based, relying on natural processes as opposed to engineering structures. It utilizes biophysical processes, such as detention, storage, infiltration, and biological uptake of pollutants, to manage stormwater quantity and quality. By including both blue and green components, the notion of BGI explicitly emphasizes the fact that aquatic and terrestrial ecosystems are interconneted, and so are water, vegetation, and soil.

While BGI is a relatively new term, the idea and practice are hardly new. It has been promoted and implemented under various terms or programmes, such as Stormwater Best Management Practices (BMPs) and Low Impact Development (LID) in the US, Sustainable Urban Drainage System (SUDS) in UK, Water Sensitive Urban Design (WSUD) in Australia, Low Impact Urban Design and Development (LIUDD) in New Zealand, ABC (Active, Beautiful and Clean) Waters Programme in Singapore, and more recently the Sponge City initiative in China. The reader can refer to Fletcher et al. (2015) for a review of some of these ideas. Here, the landscape systems associated with these programmes are all considered BGI.

In the remainder of this chapter, several common BGI systems are first introduced. We then outline the multiple ecosystem services provided by BGI and review the scientific evidence of these claimed benefits. Next we discuss the drivers behind current BGI implementation and introduce several cities that are in the forefront. Finally, we identify further BGI research agenda to better promote sustainable urban stormwater management.

10.2 Common BGI Systems

In contrast to the conventional urban drainage system, which focuses on efficient removal of stormwater runoff, it has been widely agreed upon that the more sustainable management approach is to tackle stormwater at source. BGI involves a variety of ecosystem-based landscape systems, which are designed to mimic natural hydrology and are implemented individually or in combination to manage the quantity and quality of stormwater runoff on site. It should be noted that what is perceived as sustainable stormwater management also includes measures such as permeable paving, rainwater harvesting cisterns, and underground flood storage tanks; however, here they are not considered BGI systems because they are not ecosystem-based.

10.2.1 Rain Gardens

A rain garden is a vegetated, shallow depression designed to collect and treat stormwater runoff from nearby impervious surfaces. It is also called bioretention basin. Stormwater runoff is treated through filtration, sedimentation, adsorption, and plant and microbial uptake (Lucke and Nichols 2015).

The rain garden mainly consists of the filter media and vegetation, although the detailed design varies in different bio-climatic contexts. The filter media—soil—functions not only to support plant growth but also for water quality treatment. The vegetation also functions for water quality treatment through the biofilms on the roots that adsorb pollutants. It also prevents soil erosion and keeps it porous to avoid clogging (CSIRO 2005). Native species are often used because they adapt well to the local weather and may serve as habitat for local wildlife.

Although a rain garden is often modest in size, three different planting zones should be considered: wet, moist, and dry (Hinman 2007). At the bottom is the wet zone, where the vegetation must tolerate fluctuating water levels and periodic standing water. Along the slope is the moist zone, subject to less frequent water fluctuation, and the vegetation should function for erosion control and tolerate slightly drier soil condition. At the highest elevation is the dry zone, where the soil should be well-drained and hence the vegetation must tolerate extremely dry condition.

To prevent overflow, sometimes underneath the filter media there would also be an under-drainage layer consisting of coarse sand or fine gravel, where perforated drain pipes are embedded. The under-drainage layer is designed to convey treated flows into the perforated drain pipes. However, it is also argued that the under-drainage layer could result in less filtration and poor nitrogen removal because the layer causes the filter media to become mostly aerobic, such that organic nitrogen and ammonium in the stormwater runoff are transformed into nitrate and released in the effluent (Brown and Hunt 2011).

10.2.2 Bioswales

Also a bioretention system, a bioswale is a shallow, vegetated channel used to convey stormwater runoff and treat it prior to its entry into the receiving water body. But in stormwater management a swale is used mainly for conveyance. While the bioswale is capable of treatment (Stagge et al. 2012), it is often not designed to treat the runoff to the degree to meet water quality standards, but only to filter out coarse sediment (CSIRO 2005). The bioswale is often used along the street and in the parking lot.

Similar to the rain garden, the bioswale consists of vegetation, soil, and in some cases also the under-drainage layer. What makes the bioswale different from the rain garden is its long and linear shape. It often has a parabolic or trapezoidal cross-section, with mild side slopes.

10.2.3 Constructed Wetlands

A constructed wetland is designed mainly for water quality treatment in an environmentally more controlled fashion, compared to the natural wetland. In stormwater management it can also help to slow down the flow of runoff to dampen its peak flow with its dense vegetation and relatively flat gradient.

There are two major types of constructed wetlands. One is the free water surface wetland, which consists of a series of vegetated basins, through which water flows at relatively shallow depth and low velocity; the other is the subsurface flow wetland, which is a gravel and sand-filled basin planted with vegetation, and the water level is designed to remain below the surface (Naja and Volesky 2011). The former type can be used to treat stormwater runoff, whereas the later for domestic, municipal, and industrial wastewater (USEPA 1993). As runoff enters the wetland and makes its way to the outlet, pollutants are removed through several mechanisms, including plant uptake, microbial biodegradation by biofilms, chemical adsorption, physico-chemical adsorption, mechanical filtration, and sedimentation (Naja and Volesky 2011).

10.2.4 Retention and Detention Basins

Manmade ponds have been used to intercept runoff to attenuate peak flow during an extreme storm event. There are two types of such ponds, namely detention and retention basins, or dry and wet ponds. The fundamental difference is whether there is a permanent pool of water. The detention basin has an outlet pipe at the bottom to drain the water completely after the storm, and it stays dry in between the events, hence also referred to as the dry pond; whereas the outlet pipe of the retention basin, also referred to as the wet pond, is at a higher elevation to retain some water. Traditionally, both types of basins are designed solely for stormwater management purposes. Often fenced-off and aesthetically unattractive, they are purely hydraulic structures—grey infrastructure. However, if designed creatively to be multifunctional, they can be BGI.

The retention basin, with permanent ponding, can be designed as an aesthetically pleasing water feature for the community, such as the case in the High Point redevelopment project in Seattle. Since the water is not drained quickly after the storm, the retention basin can also become a constructed wetland for water quality treatment. The detention basin, when dry, can be designed as a playground, picnic area, sports field, parking lot, etc. (Park et al. 2014). For example, the City of Elk Grove in California recently retrofitted a 2.5-ha detention basin to serve as a neighbourhood park with enhanced wildlife habitat.

10.2.5 Green Roofs

A green roof, or vegetated roof, typically consists of several layers, including vegetation, growing media, drainage layer, root barrier, and waterproofing membrane. It can absorb some rainfall falling on the roof, thereby reducing the runoff going into the downspouts.

There are two types of green roofs, extensive and intensive (Bliss et al. 2009). The extensive green roof has a thin soil layer as shallow as a few cm, often installed on a building with low load-bearing roof slab. The intensive green roof has a deeper soil layer of 15 cm or more and can support a variety of plants, including shrubs and even trees (Locatelli et al. 2014). Because of its thick substrate layer, the intensive green roof can absorb more water and hence has higher rainfall retention capacity (Mentens et al. 2006).

10.3 Multiple Ecosystem Services of BGI

Contrary to the conventional urban drainage system—grey infrastructure—that functions solely for preventing pluvial flooding, the major advantage of BGI is its multi-functionality. BGI can provide multiple benefits, or ecosystem services, including flood hazard mitigation, water quality treatment, thermal reduction, and urban biodiversity enhancement. While we focus on regulating and supporting services here, it should be noted that BGI can also deliver cultural services such as recreation, education, and aesthetic appreciation.

10.3.1 Flood Hazard Mitigation

As the city continues to expand and densify, it is increasingly difficult—space- and finance-wise—to upgrade the conventional drainage system to handle increasing runoff. As such, BGI is increasingly used to supplement the existing drainage system. BGI can intercept, retain, absorb, and evapotranspire stormwater locally to reduce the runoff going to the storm drains to overwhelm the drainage network, thereby also delaying the peak flow to mitigate downstream flood risk.

Selective research findings on the hydraulic performance of rain gardens, constructed wetlands, and green roofs are listed in Tables 10.1, 10.2, and 10.3 respectively. Most studies show that BGI is effective in flood hazard mitigation. In particular, there are extensive evidences for green roofs. While green roofs are shown to retain more rainfall than conventional roofs do, the rainfall retention rate can vary substantially (Table 10.3). It decreases as the storm progresses and the soil reaches saturation (Bliss et al. 2009). The retention rate is also affected by soil type and thickness, vegetation, slope, and age of the roof (Buccola and Spolek 2011; VanWoert et al. 2005; Getter et al. 2007).

Table 10.1 Selected research findings of the hydraulic performance of rain gardens[a]

Study	Location	Runoff reduction (%)	Peak flow reduction (%)
Dietz and Clausen (2005)	Haddam, CT, USA	98.8	–
Hirschman and Collins (2008)	Virginia, USA (computer modelling)	40–80	–
Hunt et al. (2008)	Charlotte, NC, USA	–	99
Chapman and Horner (2010)	Seattle, WA, USA	48	–
Hathaway et al. (2011)	Wilmington, NC, USA	61–63	–

[a] Rain gardens here refer to all bioretention systems, which are not necessarily called rain gardens in the studies included here

Table 10.2 Selected research findings of the hydraulic performance of constructed wetlands

Study	Location	Runoff reduction (%)	Peak flow reduction (%)
Cohen and Brown (2006)	Dade County, FL, USA	31	–
Hirschman and Collins (2008)	Virginia, USA (computer modelling)	0	–
Al-rubaei et al. (2014)	Vaxjo, Sweden	–	72
Javaheri and Babbar-Sebens (2014)	Indianapolis, IN, USA (computer modelling)	–	20–41

Table 10.3 Selected research findings of the hydraulic performance of green roofs

Study	Location	Runoff reduction (%)	Peak flow reduction
Kumar and Kaushik (2005)	Yamuna Nagar, India	–	–
VanWoert et al. (2005)	Michigan, USA	60.6	–
Berndtsson et al. (2005)	Augustenborg, Sweden	51	–
Carter and Rasmussen (2006)	Georgia, USA	50–90	18 min
Getter et al. (2007)	Michigan, USA	80.8	
Hathaway et al. (2008)	North Carolina, USA	64	>75
Hirschman and Collins (2008)	Virginia, USA (computer modelling)	45–60	–
Bliss et al. (2009)	Pennsylvania, USA	5–69	5–70
Fioretti et al. (2010)	Italy	68	89
Susca et al. (2011)	New York City, USA	–	–
Buccola and Spolek (2011)	(laboratory at Portland State University, USA)	20–65	4–8 min
Morau et al.(2012)	Reunion Island, Indian Ocean	–	–
Stovin et al. (2012)	Sheffield, UK	50.2	60
Kok et al. (2013)	Kuala Lumpur, Malaysia	–	24
Qin et al. (2013)	Singapore	11.4	65
Locatelli et al. (2014)	Denmark	43–68	0–40 min

10.3.2 Water Quality Treatment

Stormwater runoff is considered non-point source (or diffuse) pollution. As it flows through different parts of the catchment it carries with it various types of pollutants (Table 10.4). Mobile vehicles produce a considerable amount of pollutants, such as oil, grease, and tire and brake wear; and industrial activities contribute to substances eroded from open stacks of raw and finished products (Liu et al. 2015). Runoff is often of higher temperature and could increase the temperature of the receiving water body; particularly, urban water bodies are often devoid of riparian vegetation, which worsens the impact (Natarajan and Davis 2010; Susca et al. 2011). Warmer temperature can harm the aquatic organisms, especially cold-water species such as trout and salmon (Long and Dymond 2014).

Most BGI systems, except green roofs, are found effective in removing toxic chemicals, filtering sediments, breaking down bacteria, and neutralizing acidic waters. Selected research findings of rain gardens, constructed wetlands, retention and detention basins, and green roofs are listed in Tables 10.5, 10.6, 10.7, and 10.8 respectively.

Rain gardens are effective in removing most pollutants except total phosphorus (TP) and bacteria (Table 10.5). However, different rain gardens also exhibit divergent performances, probably due to different soil depths and hydraulic loadings (Hathaway et al. 2011). Constructed wetlands (Table 10.6) and retention and detention basins (Table 10.7) also exhibit various pollution reduction rates, and it can be attributed to the antecedent weather condition, rainfall intensity, and design parameters (e.g., geometry, size) (Herb et al. 2009; Al-Rubaei et al. 2014). For retention and detention basins, it also depends on residence duration of the water (Wang et al. 2004). A retention basin could have higher pollutant reduction rate if the water could have longer contact with the vegetation and sediments rich in organic matter (Mallin et al. 2002).

The pollutant removal capacity of green roofs, nevertheless, is still highly uncertain, as there are contradictory research results. In some cases, higher concentrations of total nitrogen (TN), TP, and metals are even found in the green roof outflow (Vijayaraghvan et al. 2012; Hathaway et al. 2008). In others, the green roof

Table 10.4 Common types of stormwater pollutants

Pollutant	Sources
Sediment	Soil erosion, construction sites, building weathering
Nutrients	Fertilizer, animal waste, septic system overflow Example: total nitrogen, total phosphorus
Heavy metals	Automobile exhausts, tires, fuel combustion Example: copper, iron, lead, and zinc
Bacteria	Animal waste, septic system overflow Example: *E. Coli*, faecal coliform
Toxic contaminants	Pesticides, herbicides, oil and gas leakage from vehicles

Source Bakri et al. (2008), Scholz (2015)

Table 10.5 Selected research findings on pollution reduction rates of rain gardens (the numbers are rounded up; unit in %)*

Study	Location	Heavy metal				TN	TP	Bacteria (*E. coli*)	BOD	COD	TSS
		Cd	Cu	Zn	Pb						
Dietz and Clausen (2005)						32	−111				
Hunt et al. (2006)	North Carolina, USA		99	98	81	40	−240 to 65				
USEPA (2006)	Villanova, PA, USA			74		46	28				99
Davis (2007)	Maryland, USA		57	62	83		76				47
Hunt et al. (2008)	Charlotte, NC		54	77	31	32	31	71	63		60
Hirschman and Collins (2008)	Virginia, USA, (computer modelling)					40–60	25–50				
Chapman and Horner (2010)	Seattle, WA, USA		80	80	86	63	67				87
Battiata et al. (2010)	Mechanicsville, VA, USA (computer modelling)					40–60	25–50				
Hathaway et al. (2011)	Wilmington, NC, USA							−119 to 70			
Mei and Yang (2011)	Beijing, China					31–50	47–58				
Wang et al. (2015)	(laboratory at Beijing University, China)	>90	>90		>90						

TN Total nitrogen; *TP* total phosphorus; *BOD* biological oxygen demand; *COD* chemical oxygen demand; *TSS* total dissolved solid

*Negative value represents an increase in concentration.

Table 10.6 Summary of selected research findings on pollution reduction rates of constructed wetlands (the numbers are rounded up; unit in %)

Study	Location	Heavy metal					TN	TP	Herbicide		BOD	COD	SS
		Cd	Cr	Cu	Zn	Pb			Diuron	Simazine			
Walker and Hurl (2002)	Adelaide, Australia		0	48	57	71							
Poe et al. (2003)	North Carolina, USA						30						
Cohen and Brown (2006)	Dade County, FL, USA							27					36
Hirschman and Collins (2008)	Virginia, USA, (computer modelling)						25–55	50–75					
Lu et al. (2009)	Kunming City, China						61						
Battiata et al. (2010)	Mechanicsville, VA, USA (computer modelling)						25–55	50–75					
Page et al. (2010)	Adelaide, Australia								33–51	20–60			
Scholz and Hedmark (2010)	Scotland, UK						15–98				53–93	38–71	
Zhang et al. (2011)	(laboratory at Nanchang University, China)						29–48	65–91					
Li et al. (2011)	North China						98	90				91	
Ye and Li (2009)	Ningbo, China						83	64				85	89
Babatunde et al. (2011)	Dublin, Ireland						15–76	52–100			18–88	18–84	16–93
Rai et al. (2013)	Shantikunj, Haridwar, India		35	95	55	92					90		65
Al-rubaei et al. (2014)	Vaxjo, Sweden	90	89	91	90	96	61	86					96
Beutel et al. (2014)	Yakima, WA, USA							40–60					
Lynch et al. (2014)	Virginia Beach, VA, USA						25–40	4–48					

Table 10.7 Selected research findings on pollution reduction rates of retention/detention basins (the numbers are rounded up; unit in %)

Study	Location	Heavy metal				TN	TP	Bacteria (*E. coli*)	COD	TSS
		Cd	Cu	Zn	Pb					
Middleton and Barrett (2008)	Austin, Texas, USA		55	62	69	58	52		64	91
Hirschman and Collins (2008)	Virginia, USA, (computer modelling)					25–35	20–40			
Battiata et al. (2010)	Mechanicsville, VA, USA (computer modelling)					30–40	50–75			
Rosenzweig et al. (2011)	Princeton, NJ, USA					68				
Vezzaro et al. (2012)	Stockholm, Sweden and Melbourne, Australia (computer modelling)		90	88						
Beaudry et al. (2014)	Grand Fork, ND, USA					40	73	76		76
Stanley (2015)	Greenville, NC, USA	54	26	26	55					71

Table 10.8 Selected research findings on pollution reduction rates of green roofs

Study	Location	TN	TP
Berndtsson et al. (2005)	Augustenborg, Sweden	58%	Increase
Hathaway et al. (2008)	North Carolina, USA	Increase	Increase
Hirschman and Collins (2008)	Computer modelling	0%	0%
Bliss et al. (2009)	Pennsylvania, USA	0%	Increase
Battiata et al. 2010)	Mechanicsville, VA, USA (computer modelling)	0%	0%
Stovin et al. (2012)	Sheffield, UK	–	–

behaves as a sink of TN and heavy metals (Berndtsson et al. 2009). What is slightly more certain is green roof's ability to mitigate mild acid rain through rapid neutralization of the acid deposition (Bliss et al. 2009; Viyayaraghavan et al. 2012). In any case, most researchers stress the importance of soil media composition and proper maintenance in water quality treatment (Berndtsson et al. 2005).

10.3.3 Thermal Reduction

Urban areas typically suffer from the urban heat island effect. Theoretically, BGI can cool the air temperature through evapotranspiration and shading by vegetation and the moisture-containing soil (Zhang et al. 2012). Runoff flowing through the paved surface of high thermal capacity is often warmed by conduction (Natarajan and Davis 2010). But it can be cooled during the infiltration process and as it mixes with the shallow groundwater (Erickson et al. 2013).

Green roofs are the most studied BGI systems with regard to thermal reduction performance, and they are found effective in lowering the air temperature above and below the roof, and therefore can reduce energy consumption of air conditioning (Parizotto and Lamberts 2011; Morau et al. 2012). Selected research findings are listed in Table 10.9.

There is little research on thermal reduction performance of rain gardens and constructed wetlands. It is however pointed out that the soil depth of the rain garden plays an important role to affect the temperature of the outflowing water (Jones 2008). A well-vegetated wetland might reduce thermal loads by substantial shading of the water surface (Herb et al. 2007). Retention basins can be a source of thermal pollution. This is because most water surface is exposed to direct sunlight during hot days, and as new runoff enters the pond, the previous heated water is displaced and discharged, thereby raising the temperature of the receiving water body (Herb et al. 2009; Erickson et al. 2013). However, since the retention basin reduces runoff directly discharging into the water body, it can reduce the temperature of the receiving water body at peak flow (Erickson et al. 2013).

10.3.4 Urban Biodiversity Enhancement

As changes in hydrology and biodiversity in urban areas share a common driver—land use and land cover changes, it is logical to assume that more sustainable approaches to urban stromwater management should have complementary benefits on urban biodiversity. BGI may support biodiversity by providing wildlife habitat and temporary refuges, as well as by enhancing landscape connectivity (Chester and Robson 2013; Hassall 2014).

Table 10.9 Selected research findings on thermal reduction of green roofs

Study	Location	Thermal reduction
Kumar and Kaushik (2005)	Yamuna Nagar, India	5.1 °C (indoor air)
Susca et al. (2011)	New York City, USA	2 °C (indoor air)
Morau et al. (2012)	Reunion Island, Indian Ocean	6.7 °C (roof surface)
Kok et al. (2013)	Kuala Lumpur, Malaysia	1.5 °C (indoor air)
Qin et al. (2013)	Singapore	7.3 °C (roof surface)

Tan and Ng (2015) reviewed more than fifty papers conducted from 1980 to 2015, exploring the ability of BGI to enhance urban biodiversity. Most studies report that BGI has led to increases in species of different flora and fauna groups. The strongest evidence is for aquatic faunal groups, i.e., macroinvertebrates, anuran, fish, and odonates, but there are limited studies on terrestrial faunal groups.

However, the extent of biodiversity enhancement of BGI is highly variable across different studies (Tan and Ng 2015). Moreover, few studies evaluate whether biodiversity supported locally contributes to long-term survival of metapopulations across larger geographic regions. This is possibly because of the variation of the surrounding land uses. Furthermore, different design parameters of a BGI system, such as depth of the water body, shoreline complexity, proportion of macrophytes, composition of macrophytes, and size, also exert influence on abundance and composition of biodiversity (Hamer et al. 2012; Scheffers and Paszkowski 2013). For amphibians, the combined effects of the proximity to upland supporting habitats, the characteristics of stormwater runoff received by BGI (e.g., quantity, periodicity, pollutant load), pond age, and the amount of other ponds in a larger area have been shown to be important (Birx-Raybuck et al. 2010; Holzer 2014). The potential of BGI to enhance urban biodiversity, therefore, is affected by complex interacting factors.

10.4 Drivers Behind BGI Implementation

In recent years, BGI is increasingly embraced through different initiatives in different nations and cities. The implementation of BGI has been driven by the urgency to solve different local problems or challenges. These drivers mainly include water quality standards, water security, increased flood risk, and aquatic ecosystem degradation.

10.4.1 Water Quality Standards

Where industrial and domestic wastewater discharges have been largely treated, stormwater runoff has become a major source of pollution. In US, Europe, Australia, Singapore, etc., controlling stormwater pollution has been a major challenge. Some cities adopt the combined sewer system, where stormwater runoff, along with other streams of wastewater, is delivered to the treatment plant before discharged into the receiving water body. Nevertheless, heavy precipitation events often overwhelm the system to cause combined sewage overflows (CSOs), where untreated sewage is discharged directly into the water body.

The emergence of BMPs and LID in the US was driven by the Clean Water Act, specifically, the associated National Pollutant Discharge Elimination System (NPDES) stormwater permit programme, administered by the US Environmental Protection Agency (USEPA) (Keeley et al. 2013). The permit requires stormwater runoff discharge to meet certain water quality standards, and USEPA requires the use of BMPs to meet those standards. Therefore, almost every jurisdiction in the US has adopted BMPs in the stormwater design manual by the early 1990s (Fletcher et al. 2015).

In the European Union (EU) , the Water Framework Directive (WFD) of 2000 sets the goal of attaining 'good status' for Europe's water bodies by 2015. Explicitly addressing stormwater pollution, WFD sets standards for the qualities of both runoff discharge and the receiving water body. For each water body, WFD also requires an integrated river basin management plan for achieving the 'good status', which prompted the use of SUDS by many EU members (Nickel et al. 2014).

10.4.2 Water Security

The need to control stormwater pollution can be closely linked with the issue of water supply, especially in water scarce nations. For example, Singapore's ABC Waters Programme is related to water security, which is a top priority in Singapore because of a history of water shortage (Tan et al. 2009). Surface water is a major source of water supply and is collected through a network of rivers, canals, drains, as well as 17 reservoirs across the nation. Two-thirds of this densely populated city-state function as water catchments, including built-up areas. Recognizing stormwater pollution as a threat to Singapore's water security, the ABC Waters Programme places an emphasis on using BGI systems for water quality control.

Having experienced extended droughts in recent years, Australia has shifted the focus of stormwater management from aquatic ecosystem protection to long-term water security (Morison and Brown 2011), and stormwater is considered as a source of water (Wong 2006). WSUD has evolved from a management approach to stormwater quality and quantity to a framework that integrates urban design with three 'urban water streams', i.e., potable water, wastewater, and stormwater (Wong 2006). To address water security, WSUD involves rainwater harvesting, as well as storing locally treated stormwater runoff in the aquifer.

China is also challenged by water shortage. Managing for water security is one of the major objectives of China's Sponge City initiative, which only recently started in 2014. The Sponge City initiative aims to make the city metaphorically like a sponge to be able to absorb, store, infiltrate, and purify stormwater and also be able to release water when it is needed.

10.4.3 Increased Flood Risk

While flood hazard mitigation is one of BGI's multiple functions, it is not a focus in BGI implementations in US, Europe, Australia and Singapore, mainly because the basic drainage infrastructure is already in place. However, in UK the problem of pluvial flooding plays a bigger role in its adoption of SUDS because of the concern that the existing drainage system will be increasingly inadequate in the face of climate change (Ellis 2013). Furthermore, the Flood and Water Management Act that was introduced in 2010 requires the implementation of SUDS in both new development and redevelopment projects (Ashley et al. 2013).

Increasing flood risk is a major driver behind China's Sponge City initiative because the country is still undergoing rapid urbanization. As a result of massive increases of impervious surfaces and inadequate or non-existent drainage infrastructure, in recent years numerous Chinese cities, such as Beijing, Shanghai, and Shenzhen, just to name a few, suffer frequently from severe pluvial flooding.

10.4.4 Aquatic Ecosystem Degradation

Stormwater runoff has been understood as a major threat to urban aquatic ecosystems in the developed nations, such as US and Australia. Untreated stormwater runoff not only pollutes the water body but also imposes other harms to the aquatic ecosystem. It is particularly detrimental to smaller streams because the hydrologic regime can be dramatically altered to become flashy as the conventional drainage system quickly sends runoff to the stream (Walsh et al. 2005). Although aquatic ecosystems in the urban area are subject to multiple stressors, the alteration of the hydrological regime is considered a major cause of ecological degradation (Booth 2005).

However, while most existing BGI programmes address stormwater pollution, few explicitly emphasize the wider ecological implications. An exception is Australia's WSUD, as its emergence is partly a response to the ecological degradation associated with stormwater runoff (Wong 2006). For example, Melbourne has implemented WSUD with an explicitly stated goal of 'protection of the environment, with a specific emphasis on the aquatic ecosystem including rivers, riparian zones and wetlands' (City of Melbourne 2016: 26).

Although BMPs or LID in the US generally focuses on meeting water quality standards, salmon restoration also serves as a powerful driver in the Northwest of the US, where five species of Pacific salmon are listed under the Federal Endangered Species Act. For example, Seattle's 'Green Stormwater Infrastructure' programme prioritizes basins with salmon-bearing waterways. The Seattle government and local NGOs also explicitly communicate to the general public that salmon restoration is a reason for alternative stormwater management. To promote salmon-friendly land management practices, an NGO in Portland has developed the ‘Salmon-Safe’ certification programme to acknowledge practices that keep the watershed clean enough for native salmon to spawn and thrive.

10.5 Examples of BGI Implementation in Cities

In this section we showcase four cities that are relatively more active and progressive in implementing BGI. We include Portland and New York City from the West but note that many other western cities (e.g., Melbourne, Copenhagen) also have notable achievements. Two cities from the East, Singapore and Zhenjiang, that are relatively less known for BGI, are also included to better reflect the current extent of BGI implementation across the world.

10.5.1 Portland, Oregon, USA

Striving to tackle the problem of CSO, Portland is a pioneer of BGI in the US. Its major policy is the Green Streets programme, which turns conventional streets into ‘green streets’ by installing ‘stormwater street planters’—a form of rain gardens—in the sidewalks, curb extensions, roundabouts, and traffic islands. These planters are located close to the storm drains to intercept, slow, cleanse, and infiltrate runoff to keep it out of the combined sewer system. The first green street was completed in 2003.

Portland also promotes ‘ecoroofs’, that is, green roofs. Since 1999, when the ecoroof was officially recognized as a stormwater management tool in Portland, over 560 ecoroofs have been installed, covering 15.4 ha. Any city-owned building is required to install ecoroofs to cover at least 70% of the total roof area. Incentives are also available to encourage ecoroofs on private buildings, including FAR (floor area ratio) bonus and monetary refund (US$5 for each square foot of ecoroof built).

The performances of existing BGI systems have been monitored through the Sustainable Stormwater Management Program to quantify benefits, improve design, and lower maintenance cost. According to Portland’s Bureau of Environmental Services, both ecoroofs and green streets have shown positive results in runoff reduction.

There is also the Green Street Steward Program to encourage community members to volunteer in the care and maintenance of BGI systems. To further promote BGI, the city government has partnered with local schools to install BGI systems in schoolyards for education on sustainable stormwater management.

10.5.2 New York City, USA

Also plagued by CSO, the New York City (NYC) has carried out the Green Infrastructure Plan since 2010 to reduce CSO through retrofitting streets, sidewalks, and public and private properties. The objectives are '[r]educing CSO volume by an additional 3.8 billion gallons (11.4 million m^3) per year; capturing the first 2.5 cm of rainfall from 10% of the impervious area in watersheds with combined sewers through green infrastructures; and providing substantial, quantifiable sustainability benefits, such as cooling the city, reducing energy use, increasing property values, and cleaning the air' (NYCDEP 2010).

To make BGI implementation cost-effective, the Green Infrastructure Plan identifies 'priority areas', which are drainage basins with frequent CSO incidents or high CSO volume. A major BGI system installed in the priority areas is the 'right-of-way bioswale', which tackles runoff from the public right of way. Other BGI systems include right-of-way rain gardens, stormwater green streets, green roofs, and other types of rain gardens and bioswales, all of which are considered 'green infrastructure assets'. The target of the Green Infrastructure Plan is a total of 5905 such assets, and by 2015 NYC has established 3830 assets to manage 179 ha or 0.6% of the impervious area within combined sewer tributary (NYCDEP 2015).

The GIS-based Project Tracking and Asset Management System have been established to monitor the operation and maintenance of the green infrastructure assets. There is also the NYC Green Infrastructure Co-benefits Calculator. This open access online tool allows a designer or planner to specify any type of green infrastructure asset and its parameters to estimate the cost and environmental, social and economic benefits. In addition to facilitating the process of planning and designing a green infrastructure asset, the quantification of the benefits can also facilitate stakeholder buy-ins and public outreach.

10.5.3 Singapore

Singapore has promoted BGI through the ABC Waters Programme since 2006. The objective of the programme is to transform the utilitarian drains, canals and reservoirs throughout Singapore into 'beautiful and clean streams, rivers and lakes with postcard-pretty community spaces for all to enjoy' (PUB 2014). Because almost all waterways in Singapore have been heavily channelized, managed solely for drainage efficiency, they are largely external to the everyday life of people. The ABC Waters Programme is to better integrate these waterways and other water bodies with the rest of the urban landscape to foster a sense of ownership, through improving the quality of water, physical appearance, and recreational value of the water body.

The programme addresses water quality using BGI systems, referred to as 'ABC Waters features', including vegetated swales, bio-retention swales, bio-retention basins, sedimentation basins, constructed wetlands, and cleansing biotopes. Specific and achievable water quality targets were set, subject to change over time based on monitoring results. However, an overall monitoring programme does not exist.

The ABC Waters Programme is administered by Singapore's national water authority, the Public Utilities Board (PUB). To increase the adoption of ABC Waters features throughout the nation, PUB also launched the ABC Waters Certification scheme in 2010 to encourage other public and private sectors to incorporate ABC Waters features in their development projects.

10.5.4 Zhenjiang, Jiangsu Province, China

Like other rapidly developing Chinese cities, Zhenjiang is challenged by inadequate drainage infrastructure and stormwater pollution (Sheng et al. 2011). In 2007, the Zhenjiang government began to study the idea of LID and its local implementation. Since 2010, LID measures have been incorporated into the Guantang New Town—a new urban district built from scratch, as well as the redevelopment of the old inner city area. As of 2015, Zhenjiang has built a total of 16 km of bioswales, 350,000 m^2 of green roofs, 350,000 m^2 of rain gardens, 40 km of road with pervious paving, and 1 million m^3 of rainwater storage facilities (Zhenjiang Housing and Development Bureau 2015).

In April 2015, the prior experiences on LID resulted in Zhenjiang being selected as one of the 16 'pilot sponge cities' for China's Sponge City initiative. The Sponge City initiative is backed by a strong political will top-down from President Xi Jinping with a substantial budget. The Zhenjiang Sponge City project involves a total area of 22 km^2 and 302 different sub-projects, with a total investment of RMB 8 billion (US$1.2 billion), and the ultimate goal is to tackle 75% of the total annual volume of stormwater runoff for flood safety against the 30-year storm, and to reduce non-point pollution by 60% (Zhenjiang Housing and Development Bureau 2015). It is unclear what exact BGI systems are to be built to achieve these goals. Since the Sponge City initiative is relatively new, its actual implementation and effects remain to be seen.

10.6 Future Research Agenda and Concluding Remarks

The conventional drainage system is single-functioned infrastructure that solves one problem while creating many others. BGI has been increasingly recognized as a desirable alternative, which taps into local natural processes to manage urban stormwater in a more sustainable fashion. While BGI is widely discussed in academia and increasingly practised, it is far from mainstream. Around the world, grey infrastructure continues to dominate stormwater management in existing cities, as well as new development and redevelopment projects. The major challenge today, therefore, is to mainstream BGI. Addressing the barriers to mainstreaming BGI in different cities should be an important future BGI research agenda.

However, identifying the barriers is a daunting task itself, as it depends on different socioeconomic and environmental contexts. Although different cities face different challenges of stormwater management, valuable lessons could still be drawn from existing BGI implementations, be they successful or not. Therefore, we stress the importance of conducting case studies on practical BGI experiences. In this chapter, we have touched upon several BGI programmes and reviewed various important drivers behind them. These cases, along with those not mentioned here, deserve to be studied further, particularly on the process from conception to implementation to dissemination, with a focus on the challenges and associated solutions. A good example is the study of Brown and Clarke (2007) on Melbourne's implementation of WSUD.

Furthermore, the case study should further explore the drivers behind the programme. Understanding the drivers is important because a paradigm shift often only takes place when there is a major crisis that provides the opportunity for a change. This emphasis, however, does not imply that it is impossible to mainstream BGI without some crisis. The understanding of the drivers could lead to strategies for using an existing or potential water-related problem as a leverage to promote BGI. For example, since climate change is likely to affect most cities around the world, every city would need to re-examine the resilience or robustness of its water sector to identify the current and future weak points. This could serve as an opportunity for introducing BGI to the public.

While we place an emphasis on the research on practical implementation, we note that strengthening the science behind BGI is no less important. We have reviewed the scientific evidences for the claimed benefits or ecosystem services of BGI. There remain many evident gaps in such research. While water quality treatment and flood hazard mitigation are much better researched, thermal reduction and urban biodiversity enhancement are far less understood, not to mention cultural services associated with BGI. We also do not know the relationship between these different ecosystem services. For example, would strengthening the function of water quality treatment influence the function of flood hazard mitigation? In other words, can BGI simultaneously provide multiple services equally well? Or is there tradeoff? The more we understand the actual effects of BGI, the better we know how to design BGI systems properly to make them more effective, and the better we can promote BGI with convincing evidences.

Finally, despite our focus on stormwater management, we stress that BGI should concern all water sectors, as demonstrated in the conceptualization of WSUD as a holistic urban water management approach, from water supply to wastewater treatment to stormwater management (Wong 2006). BGI can potentially be an alternative to other single-functioned water infrastructure and a framework for integrating those conventionally isolated and independent water sectors because of the multi-functionality embedded in its design. The idea of integrated urban water management is nothing new, but BGI as an integrated urban water management approach should be further explored. We believe that pushing the research frontier through identifying divers and barriers and developing integrated solutions could further contribute to urban sustainability and resilience.

References

Al-Rubaei A, Engstrom M, Viklander M, Blecken G (2014) Long-term treatment efficiency of a constructed stormwater wetland: preliminary results. In: 13th International Conference on Urban Drainage, Sarawak, Malaysia

Ashley R, Lundy L, Ward S, Shaffer P, Walker AL, Morgan C, Saul A, Wong T, Moore S (2013) Water-sensitive urban design: opportunities for the UK. Municipal Eng 166:65–76

Babatunde AO, Zhao YQ, Doyle RJ, Rackard SM, Kumar JLG, Hu YS (2011) Performance evaluation and prediction for a pilot two-stage on-site constructed wetland system employing dewatered alum sludge as main substrate. Bioresour Technol 102:5645–5652

Bakri DA, Rahman S, Bowling L (2008) Sources and management of urban stormwater pollution in rural catchments, Australia. J Hydrol 356:299–311

Battiata J, Collins K, Hirschman D, Hoffmann G (2010) The runoff reduction method. J Contemp Water Res Educ 146:11–21

Beaudry A, Lim Y, Gullicks H, Moretti C (2014) Removal efficiency of water quality pollutants in a wet detention basin in Grand Forks, ND. Thesis. Bachelor of Science, University of North Dakota

Benedict MA, Mcmahon ET (2002) Green infrastructure: smart conservation for the 21st century. Renew Res J 20(3):12–17

Berndtsson JC, Emilsson T, Bengtsson L (2005) The influence of extensive vegetaed roofs on runoff water quality. Sci Total Environ 355:48–63

Berndtsson JC, Bengtsson L, Jinno K (2009) Runoff water quality from intensive and extensive vegetaed roofs. Ecol Eng 35:369–380

Beutel MW, Morgan MR, Erlenmeyer JJ, Brouillard ES (2014) Phosphorus removal in a surface-flow constructed wetland treating agricultural runoff. J Environ Q 43:1071–1080

Birx-Raybuck DA, Price SJ, Dorcas ME (2010) Pond age and riparian zone proximity influence anuran occupancy of urban retention ponds. Urban Ecosyst 13:181–190

Bliss DJ, Neufeld RD, Ries RJ (2009) Storm water runoff mitigation using a green roof. Environ Eng Sci 26:407–417

Booth DB (2005) Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America. J North Am Benthological Soc 24(3):724–737

Brown R, Clarke J (2007) Transition to water sensitive urban design: the story of Melbourne, Australia. Report No. 07/1, Facility for Advancing Water Biofiltration, Monash University, June 2007

Brown RA, Hunt WF (2011) Underdrain configuration to enhance bioretention exfiltration to reduce pollutant loads. J Environ Eng 1082–1091

Buccola N, Spolek G (2011) A pilot-scale evaluation of greenroof runoff retention, detention, and quality. Water Air Soil Pollution 216:83–92

Carter TL, Rasmussen TC (2006) Hydrologic behavior of vegetated roofs. J Am Water Resour Assoc 42:1261–1274

Chapman C, Horner R (2010) Performance assessment of a street-drainage bioretention system. Water Environ Res 109

Chester ET, Robson BJ (2013) Anthropogenic refuges for freshwater biodiversity: their ecological characteristics and management. Biol Conserv 166:64–75

City of Melbourne WSUD Guidelines: Applying the Model WSUD Guidelines: An initiative of the Inner Melbourne Action Plan. https://www.melbourne.vic.gov.au/SiteCollectionDocuments/wsud-full-guidelines.pdf. Accessed 9 Sept 2016

Cohen WJ, Brown MT (2006) A model examining hierarchical wetland networks for watershed stormwater management. Ecol Model 201:179–193

CSIRO [Commonwealth Scientific and Industrial Research Organization] (2005) WSUD engineering procedures: stormwater [e-book]. CSIRO Publishing, Collingwood, Vic. Available from: eBook Collection (EBSCOhost), Ipswich, MA. Accessed 22 July 2016

Davis AP (2007) Field performance of biorention: water quality. Environ Eng Sci 24:8

Dietz ME, Clausen JC (2005) A field evaluation of rain garden flow and pollutant treatment. Water Air Soil Pollut 167:123–138

Ellis JB (2013) Sustainable surface water management and green infrastructure in UK urban catchment planning. J Environ Planning Manage 56:24–41

Erickson AJ, Weiss PT, Gulliver JS (2013) Optimizing stormwater treatment practices. Springer, New York

Fioretti R, Palla A, Lanza LG, Principi P (2010) Green roof energy and water related performance in the Mediterranean climate. Build Environ 45:1890–1904

Fletcher TD, Shuster W, Hunt WF, Ashley R, Butler D, Arthur S, Trowsdale S, Barraud S, Semadeni-Davis A, Bertrand-Krajewski JL, Mikkelsen PS, Rivard G, Uhl M, Dagenais D, Viklander (2015) SUDS, LID, BMPs, WSUD and more—the evolution and application of terminology surrounding urban drainage. Urban Water J 12(7):525–542

Getter KL, Rowe DB, Andresen JA (2007) Quantifying the effect of slope on extensive green roof stormwater retention. Ecol Eng 31:225–231

Hamer AJ, Smith PJ, McDonnell MJ (2012) The importance of habitat design and aquatic connectivity in amphibian use of urban stormwater retention ponds. Urban Ecosystems 15:451–471

Hassall C (2014) The ecology and biodiversity of urban ponds. Wiley Interdisc Rev Water 1:187–206

Hathaway AM, Hunt WF, Jennings GD (2008) A field study of green roof hydrologic and water quality performance. Am Soc Agric Biol Eng 51:37–44

Hathaway JM, Hunt WF, Graves AK, Wright JD (2011) Field evaluation of bioretention indicator bacteria sequestration in Wilmington, North Carolina. J Environ Eng 137:1103–1113

Herb W, Mohseni O, Stefan H (2007) A model for mitigation of surface runoff temperatures by a wetland basin and a wetland complex. Vermillion River Watershed Joint Powers Organization, Dakota County

Herb WR, Mohseni O, Stefan HG (2009) Simulation of temperature mitigation by a stormwater detention pond. J Am Water Resour Assoc 45(5):1164–1178

Hinman C (2007) Rain garden handbook for western Washington homeowners. Washington State University Extension, Tacoma

Hirschman D, Collins K (2008) Technical memorandum: the runoff reduction method. Center for Watershed Protection and Chesapeake Stormwater Network

Holzer KA (2014) Amphibian use of constructed and remnant wetlands in an urban landscape. Urban Ecosyst 17:955–968

Hunt WF, Jarrett AR, Smith JT, Sharkey LJ (2006) Evaluating bioretention hydrology and nutrient removal at three field sites in North Carolina. J Irrig Drain Eng 600–608

Hunt WF, Smith JT, Jadlocki SJ, Hathaway JM, Eubanks PR (2008) Pollutant removal and peak flow mitigation by a bioretention cell in urban Charlotte, NC. J Environ Eng 403–408

Javaheri A, Babbar-Sebens M (2014) On comparison of peak flow reductions, flood inundation maps, and velocity maps in evaluating effects of restored wetlands on channel flooding. Ecol Eng 73:132–145

Jones MP(2008) Effect of urban stormwater BMPs on runoff temperature in trout sensitive regions. PhD thesis, North Carolina State University, Raleigh, NC

Keeley M, Koburger A, Dolowitz DP, Medearis D, Nickel D, Shuster W (2013) Perspectives on the use of green infrastructure for stormwater management in Cleveland and Milwaukee. Environ Manage 51:1093–1108

Kok KH, Sidek LM, Abidin MRZ, Basri H, Muda ZC, Beddu S (2013) Evaluation of green roof as green technology for urban stormwater quantity and quality controls. IOP Conference Series: Earth and Envrionmental. Science 16:012045

Kumar R, Kaushik SC (2005) Performance evaluation of green roof and shading for thermal protection of buildings. Build Environ 50:1505–1511

Li Y, Zhang Y, Zhang X (2011) Heat preservation of subsurface flow constructed wetland in cold area in winter and its operation effect. Procedia Environ Sci 10:2182–2188

Liu Y, Bralts VF, Engel BA (2015) Evaluating the effectiveness of management practices on hydrology and water quality at watershed scale with a rainfall-runoff model. Sci Total Environ 511:298–308

Locatelli L, Mark O, Mikkelsen PS, Arnbjerg-Nielsen K, Jensen MB, Binning PJ (2014) Modelling of green roof hydrological performance for urban drainage applications. J Hydrol 519:3237–3248

Long DL, Dymond RL (2014) Thermal pollution mitigation in cold water stream watersheds using bioretention. J Am Water Resour Assoc 50(4):977–987

Lu S, Zhang P, Jin X, Xiang C, Gui M, Zhang J, Li F (2009) Nitrogen removal from agricultural runoff by full-scale constructed wetland in China. Hydrobiologia 621:115–126

Lucke T, Nichols PWB (2015) The pollution removal and stormwater reduction performance of street-side bioretention basins after ten years in operation. Sci Total Environ 536:784–792

Lynch J, Fox L, Owen JS Jr, Sample D (2014) Evaluation of commercial floating treatment wetland technologies for nutrient remediation of stormwater. Ecol Eng 75:61–69

Mallin MA, Ensign SH, Wheeler TL, Mayes DB (2002) Pollutant removal efficacy of three wet detention ponds. J Environ Qual 31:654–660

Mei Y, Yang X (2011) The effect of nutrients removal for bio-retention system in rainwater runoff. J Environ Eng 520–526

Mentens J, Raes D, Hermy M (2006) Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape Urban Plann 77:217–226

Morau D, Libelle T, Garde F (2012) Performance evaluation of green roof for thermal protection of buildings in Reunion Island. Energy Procedia 14:1008–1016

Morison PJ, Brown RR (2011) Understanding the nature of publics and local policy commitment to water sensitive urban design. Landscape and Urban Planning 99:83–92

Naja GM, Volesky B (2011) Constructed wetlands for water treatment. Compr Biotechnol 353–369

Natarajan P, Davis AP (2010) Thermal reduction by an underground storm-water detention system. J Environ Eng 520–526

Nickel D, Schoenfelder W, Medearis D, Dolowitz DP, Keeley M, Shuster W (2014) German experience in managing stormwater with green infrastructure. J Environ Plann Manage 57:403–423

NYCDEP [New York City Department of Environmental Protection] (2010) NYC green infrastructure plan

NYCDEP [New York City Department of Environmental Protection] (2015) NYC green infrastructure 2015 annual report

Page D, Dillon P, Mueller J, Bartkow M (2010) Quantification of herbicide removal in a constructed wetland using passive samples and composite water quality monitoring. Chemosphere 81:394–399

Parizotto S, Lamberts R (2011) Investigation of green roof thermal performance in temperate climate: a case study of an experimental building in Florianopolis city, southern Brazil. Energy Build 43:1712–1722

Park D, Jang S, Roesner L (2014) Evaluation of multi-use stormwater detention basins for improved urban watershed management. Hydrol Process 28:1104–1113

Poe AC, Piehler MF, Thompson SP, Paerl HW (2003) Denitrification in a constructed wetland receiving agricultural runoff. Wetlands 23(4):817–826

PUB (2014) Active, beautiful, clean waters design guidelines. PUB, Singapore

Qin X, Wu X, Chiew Y, Li Y (2013) A green roof test bed for stormwater management and reduction of urban heat island effect in Singapore. Br J Environ Clim Change 2:410–420

Rai UN, Tripathi RD, Singh NK, Upadhyay AK, Dwivedi S, Shukla MK, Mallick S, Singh SN (2013) Constructed wetland as an ecotechnological tool for pollution treatment for conservation of Ganga river. Bioresour Technol 148:535–541

Rosenzweig BR, Smith JA, Baeck ML, Jaffe PR (2011) Monitoring nitrogen loading and retention in an urban stormwater detention pond. J Environ Qual 40:598–609

Rouse DC, Bunster-Ossa I (2013) Green infrastructure: a landscape approach. American Planning Association, Chicago

Scheffers BR, Paszkowski CA (2013) Amphibian use of urban stormwater wetlands: the role of natural habitat features. Landscape Urban Plann 113:139–149

Scholz M (2015) Wetlands for water pollution control [e-book]. Elsevier Science. Accessed 22 July 2016

Scholz M, Hedmark A (2010) Constructed wetlands treating runoff contaminated with nutrients. Water Air Soil Pollut 205:323–332

Sheng JG, Zeng P, Zhang C, Yan Q (2011) Characteristics of pollution in precipitation runoff in Zhenjiang urban area. J Jiangsu Univ Sci Technol (Natural Science Edition) 25(5):496–499

Stagge JH, Davis AP, Jamil E, Kim H (2012) Performance of grass swales for improving water quality from highway runoff. Water Res 46:6731–6742

Stanley DW (2015) Pollutant removal by a stormwater dry detention pond. Water Environ Res 68 (6):1076–1083

Stovin V, Vesuviano G, Kasmin H (2012) The hydrological performance of a green roof test bed under UK climatic conditions. J Hydrol 414–415:148–161

Susca T, Gaffin SR, Dell'Osso GR (2011) Positive effects of vegetation: urban heat island and green roofs. Environ Pollut 159:2119–2126

Tan PY, Ng C (2015) Biodiversity enhancement as a goal of blue-green infrastructure development in cities. A report for research project "enhancing blue green and social performance in high density urban environments". National University of Singapore, p 76

Tan YS, Lee TJ, Tan J (2009) Clean, green and blue: Singapore's journey towards environmental and water sustainability. ISEAS Publishing, Singapore

USEPA (United States Environmental Protection Agency) (1993) Guidance manual for developing best management practices (BMP). EPA, Washington, DC

VanWoert ND, Rowe DR, Andresen JA, Rugh CL, Thomas R, Xiao L (2005) Green roof stormwater retention: effects of roof surface, slope, and media depth. J Environ Qual 34:1036–1044

Vezzaro L, Eriksson E, Ledin A, Mikkelsen PS (2012) Quantification of uncertainty in modelled partitioning and removal of heavy metals (Cu, Zn) in a stormwater retention ponds and a biofilter. Water Res 46:6891–6903

Vijayaraghvan K, Joshi UM, Balasubramanian R (2012) A field study to evaluate runoff quality from green roofs. Water Res 46:1337–1345

Walker DJ, Hurl S (2002) The reduction of heavy metals in a stormwater wetland. Ecol Eng 18:407–414

Walsh CJ, Roy AH, Feminella JW, Cottingham PD, Groffman PM, Morgan RP II (2005) The urban stream syndrome: current knowledge and the search for a cure. J North Am Benthological Soc 24(3):706–723

Wang G, Chen S, Barber ME, Yonge D (2004) Modeling flow and pollutant removal of wet detention pond treating stormwater runoff. J Environ Eng 1315–1321

Wang J, Zhang P, Yang L, Huang T (2015) Adsorption characteristics of construction waste for heavy metals from urban stormwater runoff. Chin J Chem Eng 23:1542–1550

Wong THF (2006) Water sensitive urban design—the journey thus far. Australian J Water Resour

Ye F, Li Y (2009) Enhancement of nitrogen removal in towery hybrid constructed wetland to treat domestic wastewater for small rural communities. Ecol Eng 35:1043–1050

Zhang R, Wan Y, Zhou W (2011) Simulation constructed wetland system for treating stormwater runoff in southern China. In: International conference on remote sensing, environment and transportation engineering (RSETE), 2011, Nanjing, pp 2483–2486

Zhang Y, Chen Y, Qing D, Jiang P (2012) Study on urban heat island effect based on normalized difference vegetated index: a case study of Wuhan, China. Procedia Environ Sci 13:574–581

Zhenjiang Housing and Development Bureau (2015) Developing the sponge city: Zhenjiang as a pilot city. http://jsj.zhenjiang.gov.cn/xwdt/cjxw/201503/t20150310_1440058.htm. Accessed 9 Sept 2016